MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2018/2019

EEE 3076 – POWER ELECTRONICS

(LE, EE, CE, NE)

26 OCTOBER 2018
9.00 a.m – 11.00 a.m
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 9 pages including cover page with 4 Questions only.
2. Answer ALL questions. All questions carry equal marks and the distributions of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

Question 1

a) Figure Q1 (a) shows a circuit with a diode used as a switch. The diode operates with the duty cycle of 50%. The load peak current in the circuit is assumed constant with a value of 12 A. The diode on-state resistance is 0.02 Ω and the threshold voltage of the diode is 1V. Calculate the following parameters:

(i) Power loss in diode resistive. [3 marks]
(ii) Static on-state power loss in diode [3 marks]
(iii) Total power loss for the diode. [1 marks]

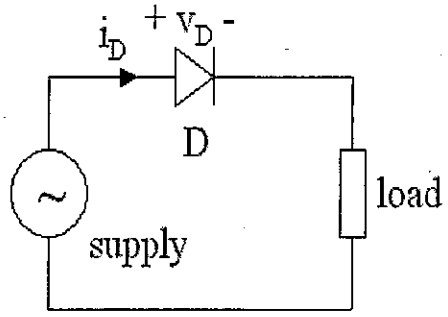

Figure Q1 (a)

b) A Power BJT (Motorola MJ10023 - Appendix A-1) is used as a switch for a DC-DC converter connected to an inductive load. The input voltage is 250 V and maximum output current is 20 A. The switch is operated at 25 kHz with 50% duty cycle. Estimate the following for the case temperature of 25°C. (Note that, $\tau_{ON} = t_d + t_r$ and $\tau_{OFF} = t_s + t_f$)

(i) Static Loss. [6 marks]
(ii) Dynamic Loss. [9 marks]
(iii) Total Loss. [3 marks]

Continued...

Question 2

a) A 9kW heater (Resistive Load) is powered by a DC supply unit. Rated voltage of the heater is 200V. The temperature of the heater is controlled by varying DC voltage (where, 50 V gives minimum temperature and 200 V gives maximum temperature). If AC supply voltage is 230 V, 50 Hz.

(i) Sketch the circuit diagram of the rectifier for the heater.

[3 marks]

(ii) Show by calculation how both the 50 V and 200 V voltage levels can be obtained.

[8 marks]

b) A load requires a three phase full bridge uncontrolled rectifier to operate. Supply voltage to the rectifier is 400V, 50Hz.

(i) Sketch the rectifier circuit diagram.

[4 marks]

(ii) Compute the load current if it is a 15kW load.

[4 marks]

(iii) One of the major problem in the rectifier circuit is failure of diode. Determine the minimum forward current and blocking voltage for the diode.

[6 marks]

Continued...

Question 3

a) Figure Q3 (a) is a boost converter circuit. Design this converter to power a load that consumes 280 W to operate. Ensure that the boost converter is operating in the continuous current mode by calculating the minimum and maximum inductor current. Assume all the components are ideal. The load requires a voltage with ripple not more than 1%. Following are other requirements :

Input voltage, $V_d = 20$ V, duty cycle, $D = 0.5$ and switching period, $T_s = 50$ µs.

[13 marks]

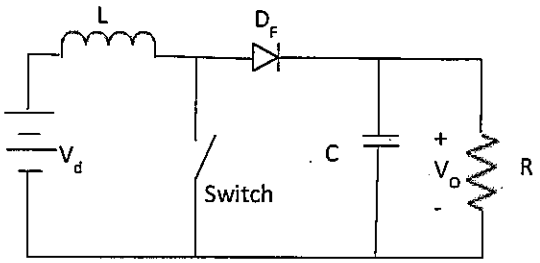

Figure Q3 (a)

b) A buck-boost converter as shown in Figure Q3 (b) is to supply a maximum power of 100W at 20 V from an input 40 V DC source. The output voltage ripple must be less than 1%. The switching frequency is 10 kHz. Assume that the converter operates at the boundary of continuous/discontinuous conduction mode when 100W is supplied.

(i) Calculate the duty cycle D. [2 marks]
(ii) Calculate the required size of the inductance L. [4 marks]
(iii) Determine the average, maximum, and minimum inductor currents. [4 marks]
(iv) Sketch the inductor current waveform. [2 marks]

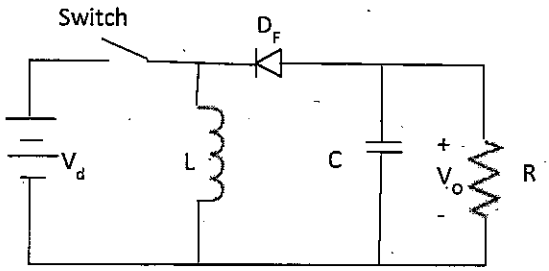

Figure Q3 (b)

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Question 4

a) A pulse width modulated full bridge inverter is shown in Figure Q4 (a). The inverter is operating at a duty cycle of 60 % with a frequency of 50 Hz.

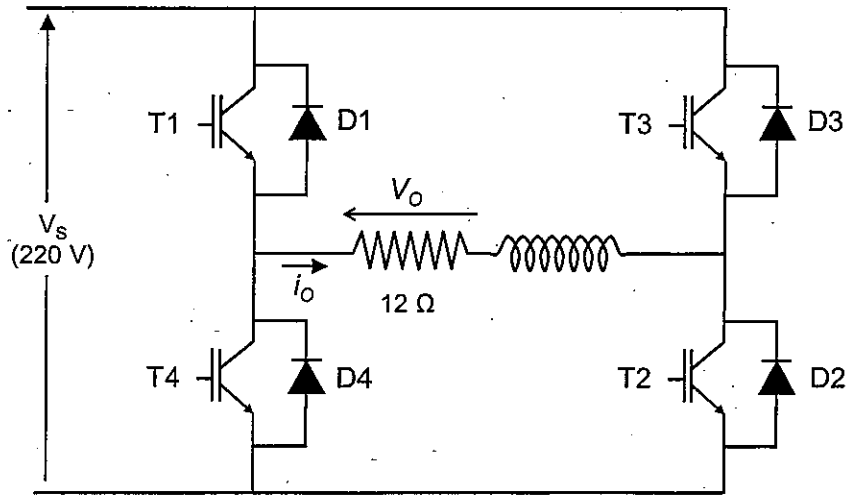

Figure Q4(a)

i) Show by calculation the percentage of third and fifth current harmonics in the inverter compared to the fundamental load current.

[13 marks]

ii) Show by calculation how to eliminate the fifth harmonic in the load current.

[5 marks]

b) In order to achieve higher output frequency (3 kHz), the circuit in Figure Q4(a) is changed to operate as a resonant inverter (a capacitor is connected in series to the load, R = 2 Ω, L = 30 μH). Calculate the minimum capacitor value so that the inverter operates in overlapping mode.

[7 marks]

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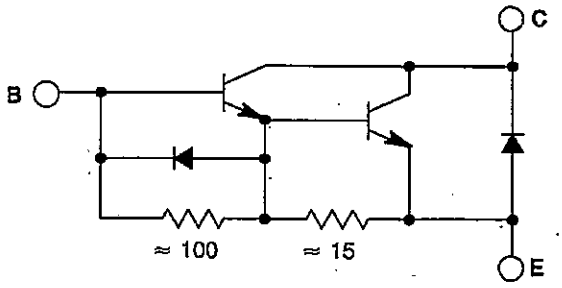
Appendix A-1

Electrical Characteristics: (T_C = +25°C unless otherwise specified)

Parameter	Symbol	Test Conditions		Min	Typ	Max	Unit
OFF Characteristics							
Collector–Emitter Sustaining Voltage	$V_{CEO(sus)}$	I_C = 100mA, I_B = 0		400	–	–	V
Collector Cutoff Current	I_{CEV}	V_{CEV} = 600V, $V_{BE(off)}$ = 1.5V		–	–	0.25	mA
			T_C = +150°C	–	–	5.0	mA
Collector Cutoff Current	I_{CER}	V_{CEV} = 600V, R_{BE} = 50Ω, T_C = +100°C		–	–	5.0	mA
Emitter Cutoff Current	I_{EBO}	V_{BE} = 2V, I_C = 0		–	–	175	mA
ON Characteristics (Note 1)							
DC Current Gain	h_{FE}	I_C = 10A, V_{CE} = 5V		60	–	600	
Collector–Emitter Saturation Voltage	$V_{CE(sat)}$	I_C = 20A, I_B = 1A		–	–	2.2	V
			T_C = +100°C	–	–	2.5	V
		I_C = 40A, I_B = 5A		–	–	5.0	V
Base–Emitter Saturation Voltage	$V_{BE(sat)}$	I_C = 20A, I_B = 1.2A		–	–	2.5	V
			T_C = +100°C	–	–	2.5	V
Diode Forward Voltage	V_f	I_F = 20A		–	–	5.0	V
Dynamic Characteristic							
Output Capacitance	C_{ob}	V_{CB} = 10V, I_E = 0, f_{test} = 1kHz		150	–	600	pF
Switching Characteristics							
Delay Time	t_d	V_{CC} = 250V, I_C = 20A, I_{B1} = 1A, $V_{BE(off)}$ = 5V, t_p = 50μs, Duty Cycle ≤ 2%		–	–	0.2	μs
Rise Time	t_r			–	–	1.5	μs
Storage Time	t_s			–	–	2.5	μs
Fall Time	t_f			–	–	1.1	μs

Note 1. Pulse Test: Pulse Width = 300μs, Duty Cycle ≤ 2%.

Circuit Outline



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Appendix A-2

MJ16018 MJW16018

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS(1)					
Collector–Emitter Sustaining Voltage (Table 1) (I_C = 50 mA, I_B = 0)	$V_{CEO(sus)}$	800	—	—	Vdc
Collector Cutoff Current (V_{CEV} = 1500 Vdc, $V_{BE(off)}$ = 1.5 Vdc)	I_{CEV}	—	—	0.25	mAdc
(V_{CEV} = 1500 Vdc, $V_{BE(off)}$ = 1.5 Vdc, T_C = 100°C)		—	—	1.5	
Collector Cutoff Current (V_{CE} = 1500 Vdc, R_{BE} = 50 Ω, T_C = 100°C)	I_{CER}	—	—	2.5	mAdc
Emitter Cutoff Current (V_{EB} = 6 Vdc, I_C = 0)	I_{EBO}	—	—	0.1	mAdc
SECOND BREAKDOWN					
Second Breakdown Collector Current with Base Forward Biased	$I_{s/b}$	See Figure 13			
Clamped Inductive SOA with Base Reverse Biased	RBSOA	See Figure 14			
ON CHARACTERISTICS(1)					
Collector–Emitter Saturation Voltage (I_C = 5 Adc, I_B = 2 Adc)	$V_{CE(sat)}$	—	—	1	Vdc
(I_C = 10 Adc, I_B = 5 Adc)		—	—	5	
(I_C = 5 Adc, I_B = 2 Adc, T_C = 100°C)		—	—	1.5	
Base–Emitter Saturation Voltage (I_C = 5 Adc, I_B = 2 Adc)	$V_{BE(sat)}$	—	—	1.5	Vdc
(I_C = 5 Adc, I_B = 2 Adc, T_C = 100°C)		—	—	1.5	
DC Current Gain (I_C = 5 Adc, V_{CE} = 5 Vdc)	h_{FE}	4	—	—	—
DYNAMIC CHARACTERISTICS					
Output Capacitance (V_{CB} = 10 Vdc, I_E = 0, f_{test} = 1 kHz)	C_{ob}	—	—	450	pF
SWITCHING CHARACTERISTICS					
Inductive Load (Table 1)					
Storage Time	t_{sv}	—	4000	8000	ns
Fall Time	t_{fi}	—	60	200	
Crossover Time	t_c	—	90	300	
Storage Time	t_{sv}	—	4500	9000	
Fall Time	t_{fi}	—	80	250	
Crossover Time	t_c	—	110	375	
Resistive Load (Table 1)					
Delay Time	t_d	—	85	200	ns
Rise Time	t_r		900	2000	
Storage Time	t_s	—	4500	9000	
Fall Time	t_f	—	200	400	

Inductive Load: Baker Clamped (I_C = 5 Adc, I_{B1} = 2 Adc, $V_{BE(off)}$ = 2 Vdc, $V_{CE(pk)}$ = 400 Vdc) PW = 25 µs; (T_J = 25°C) and (T_J = 100°C)

Resistive Load: Baker Clamped (I_C = 5 Adc, V_{CC} = 250 Vdc, I_{B1} = 2 Adc, I_{B2} = 2 Adc, R_{B2} = 3.0 Ω, PW = 25 µs, Duty Cycle ≤ 2%)

(1) Pulse Test: PW = 300 µs, Duty Cycle ≤ 2%.

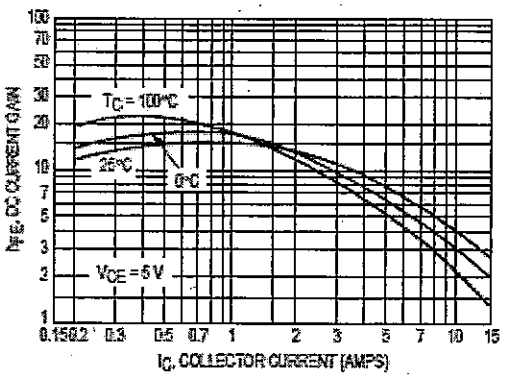

Figure 1. DC Current Gain

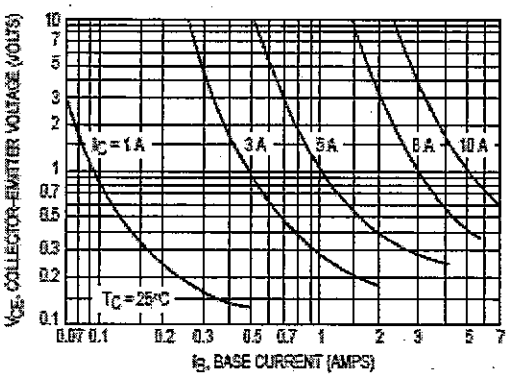

Figure 2. Collector Saturation Region

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Examination Formula Sheet (Rev 4.0)

AC-DC Converters

Single Phase Uncontrolled Rectifiers (Half wave) , R load	Single Phase Uncontrolled Rectifiers (Half wave), RL Load
$V_{o,avg} = \frac{\sqrt{2}V_{S,rms}}{\pi}$, $V_{o,rms} == \frac{V_{S,rms}}{\sqrt{2}}$	$V_{o,avg} = \frac{\sqrt{2}V_{s,rms}}{2\pi}[1-\cos(\beta)]$ $V_{o,rms} = \frac{V_{s,rms}}{\sqrt{2}\pi}\sqrt{\beta - \frac{\sin 2\beta}{2}}$ $\beta \approx \pi + \theta$, $\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$
Single Phase Uncontrolled Rectifiers (Bridge Full wave)	Three Phase Uncontrolled Rectifiers (Half wave)
$V_{o,avg} = \frac{2\sqrt{2}V_{s,rms}}{\pi}$, $V_{o,rms} = V_{s,rms}$	$V_{o_avg} = \frac{3\sqrt{3}V_{l-n}}{\sqrt{2}\pi}$, $V_{0_rms} = 1.19V_{l-n}$
Three Phase Uncontrolled Rectifiers (Full wave)	Single Phase controlled Rectifiers (Half wave)
$V_{0_avg} = \frac{3\sqrt{2}V_{l-l}}{\pi}$, $V_{0_rms} = 0.963\ V_{l-l}$	$V_{0_avg} = \frac{V_{S,rms}}{\sqrt{2}\pi}(1+\cos\alpha)$ R Load $V_{0_avg} = \frac{V_{S,rms}}{\sqrt{2}\pi}(\cos\alpha + \cos\beta)$ RL Load
Single Phase controlled Rectifiers (Bridge Full wave)	Three Phase controlled Rectifiers (Half wave)
$V_{0_avg} = \frac{\sqrt{2}V_{S,rms}}{\pi}(1+\cos\alpha)$ R Load $V_{0_avg} = \frac{2\sqrt{2}V}{\pi}\cos\alpha$ RL Load	$V_{0_avg} = \frac{3\sqrt{2}}{2\pi}V_{AN}\left(1+\cos\left(\pi/6+\alpha\right)\right)$
Three Phase controlled Rectifiers (Full wave)	
$V_{0_avg} = \frac{3\sqrt{6}}{\pi}V_{AN}\cos\alpha$	

DC-DC Converters

Buck Converter (CCM)	Buck Converter (DCM)
$V_o = DV_d$ $I_{L\max} = V_o\left[\frac{1}{R} + \frac{(1-D)}{2Lf_s}\right]$ $I_{L\min} = V_o\left[\frac{1}{R} - \frac{(1-D)}{2Lf_s}\right]$	$\frac{V_o}{V_d} = \frac{D}{D+\Delta_1}$ $I_o = \frac{V_d T_s}{2L}D\Delta_1$

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DC-DC Converters (cont.)

Boost Converter (CCM)	Boost Converter (DCM)
$V_o = \frac{V_d}{1-D}$ $I_{L\max} = \frac{V_d}{(1-D)^2 R} + \frac{V_d D T_s}{2L}$ $I_{L\min} = \frac{V_d}{(1-D)^2 R} - \frac{V_d D T_s}{2L}$	$\frac{V_o}{V_d} = \frac{\Delta_1 + D}{\Delta_1}$ $I_o = \frac{V_d T_s}{2L} D\Delta_1$
Buck-Boost Converter (CCM)	**Buck-Boost Converter (DCM)**
$V_o = \frac{V_d D}{1-D}$ $I_{L\max} = \frac{V_d D}{R(1-D)^2} + \frac{V_d D T_s}{2L}$ $I_{L\min} = \frac{V_d D}{R(1-D)^2} - \frac{V_d D T_s}{2L}$	$\frac{V_o}{V_d} = \frac{D}{\Delta_1}$ $I_o = \frac{V_d D}{2 f_s L}(D + \Delta_1) - \frac{D I_o}{\Delta_1}$
Flyback Converter (CCM)	**Flyback Converter (DCM)**
$\frac{V_o}{V_d} = \frac{N_2}{N_1}\frac{D}{1-D}$ $I_{L\max} = \frac{V_d D}{R(1-D)^2}\left[\frac{N_2}{N_1}\right]^2 + \frac{V_d D T_s}{2L_m}$ $I_{L\min} = \frac{V_d D}{R(1-D)^2}\left[\frac{N_2}{N_1}\right]^2 - \frac{V_d D T_s}{2L_m}$	$\frac{V_o}{V_d} = D\sqrt{\frac{R}{2 f_s L_m}}$ $I_o = \frac{V_o}{R}$

DC- AC Converters

Single-Phase Half-bridge Inverter with RL load	Resonant Converters
$v_o(\omega t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{2V_s}{n\pi}\sin(n\omega t)$ Single-phase full-bridge PWM inverter (Square Wave) $v_o(\omega t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_s}{n\pi}\sin(n\omega t)$ Single-phase full-bridge PWM inverter (Quasi Square Wave) $v(\omega t) = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_s}{n\pi}\sin\frac{nD\pi}{2}\cos n(\omega t - \frac{D\pi}{2})$	$\omega_r = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$ $i(t) = \frac{V_s + V_c}{\omega_r L} e^{-\alpha t}\sin\omega_r t \quad , \ \alpha = \frac{R}{2L}$ $V_c = V_s\left(\frac{e^{2z}-1}{e^{2z}+1}\right), z = \frac{\alpha\pi}{\omega_r}$ $V_{cp} = V_s\left(1 + \frac{2e^{2z}}{e^{2z}+1}\right)$

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